Pulsar surveys with the xNTD

Simon Johnston and Russell Edwards

Australia Telescope National Facility, CSIRO, PO Box 76, Epping, NSW 2121, Australia

[VERSION 2.0 of September 1, 2006]

Abstract

We show that it is possible to perform an all-sky pulsar survey with the xNTD which is some 30 times more sensitive than the previous all-sky survey carried out using Parkes. The computing requirements dictate that this survey would be insensitive to millisecond pulsars with periods less than about 25 ms. However, the survey would detect some 1600 pulsars of which about half would be new discoveries. A number of these could be exotic objects, such as double neutron star system, pulsars with high mass companions, mildly relativistic pulsars and perhaps even a pulsar-black hole system. The survey would also be sensitive to transients, particularly to those such as occur in the newly discovered RRAT objects.

1 Motivation

The Extended New Technology Demonstrator (xNTD) is the Australian SKA Demonstrator. One of the science drivers of this instrument is the detection of exotic pulsars made possible by a large scale survey.

This short note attempts to set out how best to conduct a pulsar search on the full Field-of-View (FoV) of the xNTD (or indeed any interferometer). Traditionally pulsars survey have not been carried out using interferometers because of the ferocious storage and computing requirements. We will show here that the 'ultimate' search of pulsars is likely not possible with the xNTD but that a scientifically useful survey can be carried out by carefully restricting the parameters.

2 Survey Sensitivity

Consider the xNTD has N dishes (nominally 30) with diameter D (nominally 12 m) and has a configuration with a maximum baseline L (nominally 1 km). The total number of baselines, B, is

$$B = 0.5 \times N \times (N - 1) \quad (1)$$

and is then nominally 435 for the xNTD. The approximate number of pixels (synthesised beams) within the primary FoV is given by

$$P = \left(\frac{L}{D}\right)^2 = 6.9 \times 10^3 \left(\frac{L}{1\mathrm{km}}\right)^2 \left(\frac{12\mathrm{m}}{D}\right)^2 \tag{2}$$

The xNTD will have multiple fields of view (M; nominally 30) yielding a total field of view F, and the system temperature, T, is nominally 50 K.

We can compare an xNTD survey with any other pulsar survey by noting that the survey speed of a telescope is given by

$$SS \propto A^2 \;\; T^{-2} \;\; F \;\; BW \tag{3}$$

where A is the total collecting area and BW is the total bandwidth. In particular we can take two examples of recent Parkes ($D = 64$m) surveys. The first is the Parkes multi-beam pulsar survey at 1.4 GHz with T of 22 K, F of 0.65 and BW of 288 MHz. This survey detected 800 new pulsars and covered a strip 10 degrees wide centered along the galactic plane with integration times of 35 min per pointing. We denote this survey as PH. The second survey is the Parkes all-sky survey conducted at 436 MHz with T of 80 K, F of 0.8 and BW of 32 MHz. That survey, although it integrated for only 3 mins per pointing detected many millisecond pulsars. We denote this survey as PL. Then,

$$\frac{\mathrm{xNTD}}{\mathrm{PH}} \propto \frac{N^2 D^4}{64^4} \;\; \frac{22^2}{T^2} \;\; \frac{F}{0.65} \;\; \frac{256}{288} \tag{4}$$

$$\frac{\mathrm{xNTD}}{\mathrm{PL}} \propto \frac{N^2 D^4}{64^4} \;\; \frac{80^2}{T^2} \;\; \frac{F}{0.8} \;\; \frac{256}{32} \;\; \frac{1000^{-1.5}}{436^{-1.5}} \tag{5}$$

where we have made a correction for the different frequencies of the surveys in the latter part of the equation 5. For the parameters listed above means the xNTD covers the sky some 13x faster than the PH survey and 350x faster than the PL survey.

If we then want to cover every point in the sky to the same sensitivity as the PH survey achieved, the observation time of xNTD is longer by all the factors in the above equation except that involving F, or a factor of 4.2. As the PH survey's integration was 35 min, the xNTD needs 150 mins per pointing. This implies that for F=40 square degrees, we can survey 30,000 square degrees of sky in 750 pointings for a total of $\sim$2000 hrs observing. This survey would be some 30 times more sensitive than the PL survey.

3 Computing requirements

The only sensible way to conduct a pulsar survey using current computing costs is to use the standard imaging correlator to produce the sky visibilities and dumping the data at a fast rate. This produces $M \times B$ 'streams' of data which much be recorded and processed.

In a pulsar survey we want to overcome the effects of dispersion as far as possible by subdividing the total band into narrow channels. The sampling time and the channel width are related; very fast sampling also requires very narrow channels. Also, a survey is required to search the dispersion measure (DM) parameter space. The narrower the channels, the finer the DM steps need to be which therefore increases the total computational load. Furthermore, the faster the sampling rate, the more samples there are per given time and the longer the subsequent Fourier transform needs to be, again increasing the computational load. We can write the link between the number of channels, c, the sampling rate in Hz τ and the observing frequency f, via

$$c = 8300 \;\; DM_0 \;\; BW/f^3 \;\; \tau \tag{6}$$

where DM_0 is the DM at which the time smearing per channel is equal to the sampling rate and should be in the range 20 - 200.

With the number of bits per sample as b, the total data rate in bits per second for all streams is

$$\mathrm{DR} = \tau \times c \times b \times M \times B \tag{7}$$

The ideal survey might require $b = 8$, $c = 512$, $\tau = 10000$ (giving DM_0 as 25). This gives an output data rate of $\sim$65 Gbytes/sec. This is clearly a ridiculous number by a factor roughly $\sim$1000 and we therefore need to reduce all of b, c, and τ by substantial amounts.

A more realistic survey might then have $b = 2$, $c = 64$, $\tau = 200$ (DM_0 = 150) yielding a data rate of $\sim$40 Mbytes/sec. A single pointing lasting 180 mins would therefore use $\sim$450 Gbytes of disk storage. (Note this number is comparable to the maximum data rate expected from spectral line observing with 4 polarizations, $b = 8$, $c = 64,000$, $\tau = 0.03$).

Data processing involves first forming a time series for a given pixel within each primary beam (computationally cheap). Then, standard pulsar search techniques (de-dispersion, fourier transform, harmonic summing and searching) can be carried out for each DM step for each pixel. The estimated time for the standard pulsar search (using 150 DM steps) is 10 mins on a current 2.2 GHz pentium processor. We will assume an xNTD processor is 10x faster than this, and so processing takes about 1 min per pixel. The total processing time is therefore

$$PT = 1\mathrm{min} \times \frac{P \times M}{N_{\mathrm{nodes}}} \tag{8}$$

and so for a 100 node machine, processing an entire pointing of 7000 pixels in each of 30 beams would then take 35 hrs, or some 10x real time, about standard for pulsar surveys but still uncomfortably long for a 100 day survey. We have not taken into account acceleration searches which may be necessary because of the long integration time, but these are generally not required for long period pulsars.

4 Science

Since the late 1980s, pulsar surveys have concentrated on finding millisecond pulsars (MSPs). There are now some 200 MSPs known, about half of which are in globular clusters. The timing stability of MSPs is excellent and this makes them the obejcts of choice for tests of general relativity, possible detection of gravity waves and so on. As outlined above, a full scale survey for MSPs is likely not an option with the initial computing facilities available to the xNTD.

We have carried out a simulation using the parameters for the ‘slow’ pulsar survey covering the sky from declination -90 to +30. The survey would detect 1600 pulsars, about half of which would be new discoveries. Many of the new detections would be low luminosity objects and would help categorise the logN-logS distribution. A bigger sample of pulsars is also useful for (a) deriving an electron density distribution of the Galaxy, (b) determining the Galactic magnetic field (c) understanding the polarization properties.

Furthermore, many exotic objects are slow spinning, including the original binary pulsar B1913+16, the pulsars with high mass companions, and relativistic system such as J1141$-$6545. It is likely that any pulsar companion to a black hole will be slow spinning, and the xNTD survey might find such an object. Finally, the survey would be sensitive to transients with pulse widths greater than 10 ms or so. It would certainly detect a substantial population of RRATs, a newly discovered class of neutron stars.

5 xNTD parameters

As we have seen above, to minimise the computational needs for a pulsar survey we need to minimise the number of pixels that need to be processed by reducing the effective maximum baseline length. The same survey would be 4x less computational load if the same collecting area were placed inside 500 m rather than the 1 km used above. Unfortunately, other science drivers are pushing the maximum baseline of the xNTD outwards. In particular, the HI survey requires baselines up to 2.5 km and continuum surveys would ideally have 10 km baselines. This has major repercussions for the pulsar survey.

It is possible that the xNTD parameters could change, depending on the overall budget available. One can envisage that the survey speed of the xNTD could increase by a factor of 4 either by doubling the number of dishes (collecting area) or by a factor 4 increase in the field of view. For a pulsar survey, it is far better from the computer processing point of view to increase the collecting area rather than the field of view. When the field of view is increased, the total observing time goes down but the processing time remains constant because the instantaneous sensitivity has not increased. In contrast, increasing the collecting area reduces both the survey time and the processing time. In both cases the amount of storage required increases.

It is difficult to see how to increase $c = 64$ and $\tau = 200$ in the short term. To make a difference both would have to increase by a factor of at least 3, with the resultant increase in the data rate and computation by a factor 10.

6 Summary

We have shown that it is very difficult to envisage a full-blown survey for millisecond pulsars using the xNTD. The data storage and processing requirement are nearly two orders of magnitude larger than we could afford (even in 2010). However, it is more straightforward to imagine a very sensitive all-sky survey for slow pulsars. Such a survey would discover up to 1000 pulsars with the resultant implications for galactic modelling. Some of the new pulsars will be exotic systems generating new and exciting results in their own right. Many transients such as the RRATs would undoubtedly be discovered.

Acknowledgments

We thank Dunc Lorimer for running the simulations.